# Assessment of the Fertilizer Potential of Distillers' Grains from Wheat-Based Ethanol Production

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## Abstract

A surplus of distillers' grain resulting from rapid expansion in biofuel production has led to interest in finding alternative uses for this co-product apart from its traditional use as an animal feed. Land application to agricultural soil in order to recycle the nutrients is one potential use. In this study we evaluated the effect of a single application of wet wheat distillers' grain (WDG) on crop yield and nitrogen and phosphorus uptake in a three-year canola-wheat-canola rotation in southern Saskatchewan. The experimental treatments included a single application of WDG at a rate of 100 kg N ha$^{-1}$ in comparison to urea applied at the same rate of N along with an unfertilized control. In the first year, WDG produced a canola yield of 1266 kg ha$^{-1}$ that was significantly higher than the urea treatment. The WDG treatment resulted in higher plant N uptake that was 59 % higher than the control, but was 20 % less than that observed in the urea treatment, indicating that only a portion of the applied N in the WDG was available for recovery. Higher yield of WDG is attributed to a benefit of other nutrients in addition to N. Both WDG and urea treatments had a significant effect on plant P uptake in the first year. The residual effect of WDG addition on crop parameters in the second and third years was mainly limited to enhancement of plant P uptake. Overall, the WDG applied at the same rate of N was as effective in increasing crop yield as urea.

## Introduction

Distillers' grain (DG) is a major byproduct of bioethanol production from starch crops. The continual rise in energy demand has led to a global expansion in biofuel production from sustainable sources, resulting in large amounts of associated byproducts being generated. One tonne of wheat generates 372 L of ethanol and 457 kg wet distillers grain or 295 kg of dried distillers grain with solubles whereas one tonne of corn produces 378 L of ethanol plus 479 kg wet distillers grain or 309 kg of dried distillers grain with solubles (Bonnardeaux, 2007). In 2012, USA ethanol biorefineries produced more than 34 million Mg of distillers grains (RFA, 2013b). In 2009, ethanol plants in western Canada generated 0.46 million Mg of dried distillers grain with solubles (University of Saskatchewan, 2009).

The distillers' grain has been commonly used as animal feed due to its higher content of protein and nutrient (e.g. Gibb et al., 2008; Harris et al., 2008). However, high concentrations of fiber and nutrient, especially phosphorus can limit the use of distillers grain mainly to ruminant diets, and the high phosphorus content could pose manure disposal challenges for cattle producers (Raush and Belyea, 2006), due to a greater land area required for application to avoid phosphorus loading in the soil. This higher content of P, fiber and protein is greater than that needed in the animal diets (Noureddini et al., 2008), and the excess nutrient in animal diets will be excreted in the urine and fecal material. Therefore, it is sometimes recommended to restrict inclusion of distillers grain in animal diets to a certain ration, for example 20% of the diet (Hao et al., 2009). As a result, feeding distillers grain to animals may not accommodate continued rise in distillers grain production, as the rapid growth in the ethanol industry is expected to create a surplus of dried distillers grain with solubles (Erickson et al., 2005; Rausch & Belyea, 2006). Therefore, alternative approaches to their utilization need to be considered, including direct land application as a fertilizer and soil amendment. However, the option of land application of ethanol production byproducts has received little attention, and very few studies have looked at this option in the past. Recent controlled environment studies found that addition of wet distillers' grain to a Brown Chernozemic soil of Saskatchewan contributed to higher crop production and nutrient release (Qian et al., 2011; Alotaibi and Schoenau, 2013). Clarification of these findings on a larger scale under field conditions is needed. Therefore, the objective of the current study was to evaluate the direct and residual effect of wet distillers' grain application on crop yield and nutrient uptake over a period of 3-years in a canola-wheat-canola rotation in the field.

## Materials and Methods

### Experimental Site

The experiment was carried out on agricultural land in a canola-wheat rotation located near the town of Central Butte (50°47′31″ N lat, 106°30′28″ W long) in south-central Saskatchewan. The soil at this site was classified as Orthic Brown Chernozem (Soil Association: Ardill Loam), with a loamy texture and nearly level topography. The field at this site was cropped to hard red spring wheat in the year prior to the current study. Immediately after experimental plots were laid out in spring of 2009, selected soil properties to characterize site were determined on soil samples collected across the study area from the control plots at three soil depth (0-15, 15-30 and 30-60 cm) increments (Table 1). The soil is deficient in available N and P, sufficient in K, and with low organic matter content and high pH. The soil is non-saline.

### Experimental Design

This field experiment is part of a field trial initiated in spring 2009 to evaluate the effectiveness of a range of biofuel production byproducts as soil amendments. For this study, the experimental plots were laid out with a dimension of 2 m × 2 m for each plot, to which the treatments were immediately applied. The limited amount of available wet distillers' grain dictated the plot size. The experimental treatments included one rate of wet distillers' grain (WDG) applied alone at 100 kg N ha$^{-1}$, one rate of urea fertilizer applied at 100 kg N ha$^{-1}$, which is the typical rate of N applied and an unamended/unfertilized plot (control). The assigned treatments were applied in a completely randomized design and replicated four times. The amendments were added only once in spring 2009, but the carryover effects of treatments were monitored for the subsequent three growing seasons (2009-2011).

**Table 1.** Selected characteristics of the field soil (0-15 cm depth) determined at the beginning of the trial in spring 2009.

| Property | Value† |
|---|---|
| $NO_3^-$-N (mg $kg^{-1}$) | 3.9 ± 0.9 |
| $NH_4^+$-N (mg $kg^{-1}$) | 2.6 ± 0.1 |
| Avail. P (mg $kg^{-1}$) | 10.6 ± 1.4 |
| Avail. K (mg $kg^{-1}$) | 348 ± 36 |
| OC (%) | 1.1 ± 0.1 |
| pH | 7.9 ± 0.1 |
| EC (dS $m^{-1}$) | 0.1 ± 0.0 |

† Values presented are means ($n$ = 4) followed by standard error

### Amendment Preparation and Application

The WDG was obtained from a wheat-based ethanol production facility at Lanigan, Saskatchewan. A homogenous subsample of WDG was collected and sent to a commercial laboratory (ALS Laboratory Group, Saskatoon, SK) to determine its nutrient content. Selected characteristics of the WDG are provided in Table 2. Prior to field application, the bulk WDG was homogenized by manual mixing. It was weighed, bagged and broadcast applied by hand. Immediately after the application and prior to seeding, amendment treatments were incorporated with a tandem disk to a depth of 5 cm. The same day, canola (*Brassica napus* var. Invigor 5030) was seeded on May 21st, 2009 at a rate of 5.6 kg $ha^{-1}$ using a John Deere 610 air seeder at 30 cm row spacing and 2 cm depth. On May 16th, 2010, unfertilized Hard Red Spring Wheat (var. Waskeda) was seeded at a rate of 75 kg $ha^{-1}$. On May 1st, 2011, a blanket application of fertilizer was made across the site at a rate of 45 kg N $ha^{-1}$ and 12 kg $P_2O_5$ $ha^{-1}$ as pre-plant banded fertilizer. Then, plots were seeded with canola (var. Invigor 5030) on May 10th, 2011 at rate of 5 kg $ha^{-1}$. At the time of seeding, an additional 20 kg N $ha^{-1}$ and 10 kg $P_2O_5$ $ha^{-1}$ were applied with the seed in the seed-row.

### Plant Sample Collection and Analysis

Crops were harvested in late August of each year at physiological maturity. Plant samples from one square meter (1-$m^2$ samples) were cut manually 5 cm above the soil surface. The samples were dried by forced air at 45 °C, and mechanically threshed to determine seed and straw yield. Straw samples were ground to < 2 mm in a Wiley™ mill and wheat grain samples were finely ground with a Cyclone™ mill. Total N and P were measured by digesting the canola seed and ground wheat grain and straw samples in sulfuric acid-peroxide ($H_2SO_4$-$H_2O_2$) using a temperature-controlled digestion block (Thomas et al. 1967), followed by automated colorimetry for determination of P and the $NH_4^+$-N using Technicon Autoanalyzer II (Technicon Industrial Systems 1973). Total N and P uptake were then calculated from plant N and P contents and total dry matter yield. The total N and P uptake was not determined in crop samples collected in the final year of 2011.

**Table 2.** Basic characteristics of wet distillers' grain used in the field study.

| Property | Value |
|---|---|
| Organic C (%) | 49.5 |
| TN (%) | 0.93 |
| TP (%) | 0.13 |
| K (%) | 0.13 |
| S (%) | 0.10 |
| Na (mg $kg^{-1}$) | 320 |
| Ca (mg $kg^{-1}$) | 495 |
| Mg mg $kg^{-1}$) | 605 |
| Cu (mg $kg^{-1}$) | 3.1 |
| Fe (mg $kg^{-1}$) | 59.5 |
| Mn (mg $kg^{-1}$) | 14.8 |
| Zn (mg $kg^{-1}$) | 12.3 |
| Moisture (%) | 79 |

Organic C is expressed on a dry basis.
All nutrient contents are expressed on a wet basis.

**Statistical Analysis**

Results for each variable are reported as the mean ± standard error of four replicates per treatment. Prior to data analysis, raw data were subjected to normality and homogeneity of variance tests using Shapiro-Wilk and Bartlett tests, respectively. Then, a one-way analysis of variance (ANOVA) was employed to analyze treatment effects on plant variables. Treatments effects were declared statistically significant at a probability level of $P \leq 0.05$ at which means were also separated by Fisher's protected LSD. Due to differences in the crop type, the analysis was performed on data from each year separately.

**Results and Discussion**

The effect of WDG addition on crop yield was evident in the first year following application, where WDG treatment resulted in canola yield that was significantly higher than for the urea treatment (Fig. 1). However, the WDG treatment did not have any significant residual effects on crop yield (wheat followed by canola) during the following two years (Fig. 1). The significant impact of WDG on crop yield in the first year can be related to high availability of its N which appears to be readily mineralized to plant available inorganic nitrogen. In addition, the content of other essential plant nutrients in WDG, such as P and S may have also contributed to higher yield when compared to urea fertilizer added at the same rate of N. In a field study conducted in

Novelty, Missouri, Nelson et al. (2009) reported that dried distillers' grain was an effective fertilizer in supplying nutrient to corn crops, providing similar yield to that of urea and anhydrous ammonia. Moreover, high availability of N in dried distillers' grain was demonstrated under controlled environment conditions (Moore et al., 2010).

Addition of WDG significantly increased canola plant N uptake in the first year when compared to the control, but no residual effect was observed in the following year (Fig. 2). However, the N uptake in WDG treatment was significantly lower than that in the urea treatment (Fig. 2), reflecting that only a portion of the N in the WDG was rendered available in the year of application. This is due to the very readily N in urea fertilizer compared to the organic amendment of WDG. The higher yield observed with WDG treatment compared to the urea added at the same rate of total N therefore may be related to supply of other nutrient, especially P and S. Under controlled environment conditions, Qian et al. (2011) found that, at equivalent rate of N application, N uptake in WDG treatments were lower than that in urea treatments, and was attributed to partial mineralization of organic N in WDG. Total plant P uptake was significantly affected by treatments application, with both WDG and urea treatments providing similar P uptake that was significantly higher than the control (Fig. 2). The WDG applied in the first year did contribute to a significant increase in P uptake in the second year (Fig. 2). This is a consequence of the narrow N:P ratio in WDG, resulting in excessive supply of P that exceeds crop demand in the year of application, when the amendment is applied based on N requirement. The crop grown in the second year likely benefited from the unused P from the first year..

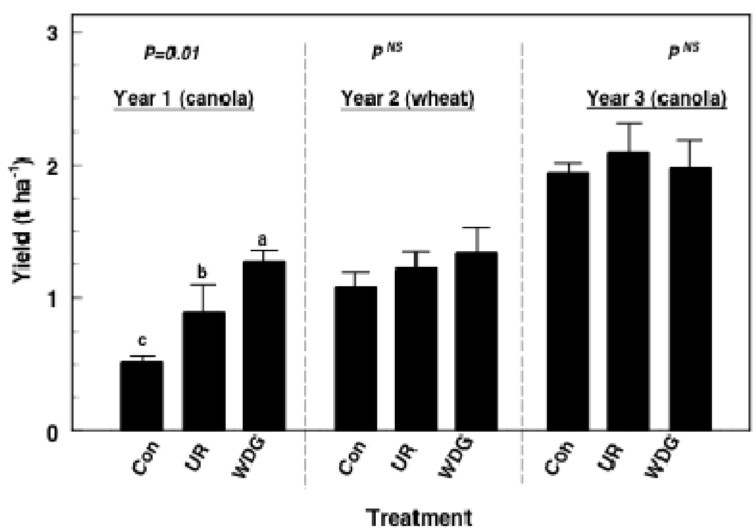


**Fig. 1.** Yield responses to treatment application in a canola-wheat-canola rotation on a Brown Chernozem in south-central Saskatchewan. Treatments were applied once in spring 2009 at the start of the rotation and were control (Cont) without amendment, urea (UR) added at 100 kg N ha$^{-1}$, and wet distillers' grain (WDG) added at 100 kg N ha$^{-1}$. For a year, bars sharing the same letter among treatments are not significantly different according to LSD test ($P \leq 0.05$). Error bars represent standard error of mean ($n$ = 4). *NS* denotes not significant at $P \leq 0.05$.

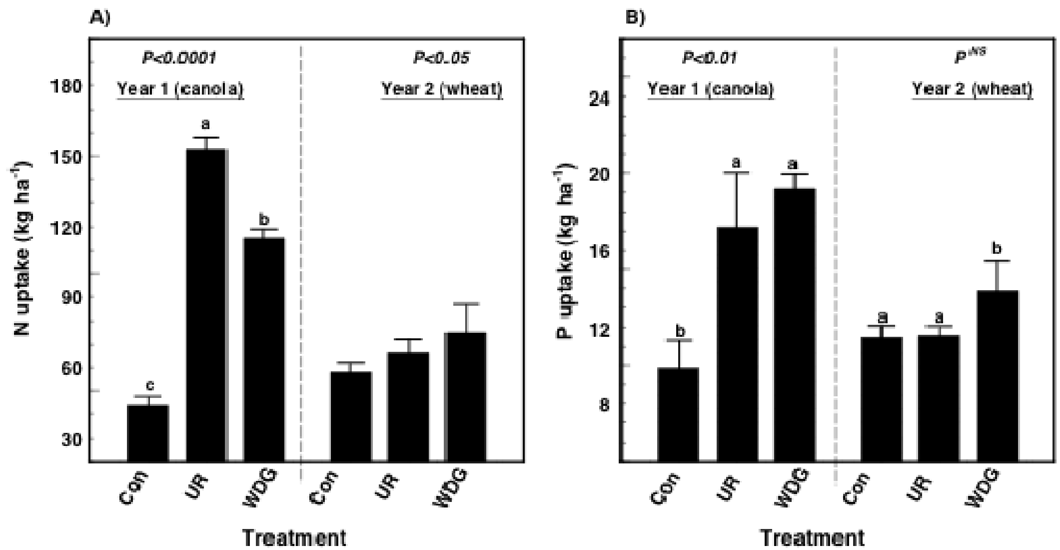


**Fig. 2.** Total plant N uptake (A) and total plant P uptake (B) responses to treatment application in year 1 (canola) and year 2 (wheat) grown in a field trial on a Brown Chernozem in south-central Saskatchewan.. Treatments were applied once in spring 2009 and were control (Cont), urea (UR), and wet distillers' grain (WDG). For a year, bars sharing the same letter among treatments are not significantly different according to LSD test ($P \leq 0.05$). Errors bars represent standard error of mean ($n = 4$). *NS* denotes not significant at $P \leq 0.05$.

## Conclusion

Wet distillers' grain derived from wheat-based ethanol production can be utilized as a fertilizer to provide essential nutrients for crop growth to enhance yield. The WDG would require a higher rate of application in the first year than employed in this study in order to have effects persist into the following growing seasons.

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